UNIVERSITY OF HAWAII MANOA

MASTERS THESIS

Sufficient Eye Protection for the 2017 American Eclipse

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Declaration of Authorship

I, Anastacio T. DALDE III, declare that this thesis titled, “Sufficient Eye Protection for the 2017 American Eclipse” and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
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Abstract

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Masters

Sufficient Eye Protection for the 2017 American Eclipse

by Anastacio T. DALDE III

On August 21, 2017 the skies will host America to an exclusive command performance commonly referred to as "The Great American Eclipse." In the astronomy world our country has won the lottery and has been given the astronomical equivalent privilege of hosting the World Cup, Olympics, and the Super Bowl all within a 94 minute window. The author has previously published a paper entitled "2017 Solar Eclipse-Prevention of Solar Retinopathy or "Eclipse Blindness"" in a VRC newsletter on January 2017. Many people have responded to the article inquiring about what is considered "safe" when purchasing "Eclipse Glasses." Choosing the wrong eye protection could lead to permanent damage to the retina. There are many on the market that claim to be safe, however there are some that are not safe and could lead to eye damage despite the manufacturer's claims. There are distinguishing markings or certifications that manufacturers will put on their glasses or advertise with their glasses. Some of these include ISO 12312-2, CE, and ANSI Z87. Most people do not know what these markings mean and how they apply to solar eye protection. This research has collected data on twenty six different pairs of glasses from a wide variety of manufacturers. The author will publish a tri-fold brochure which will summarize the data and explain what some of these markings are to help the general population choose the safest eye protection to use for viewing an eclipse. This thesis will further explore the findings and explain how the data was processed and interpreted.

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List of Abbreviations

ANSI	**A**merican **N**ational **S**tandards **I**nstitute
OD	**O**ptical **D**ensity
ISO	**I**nternational **O**rganization for **Standardization**
CE	**C**onformité **E**uropéene
NASA	**N**ational **A**eronautics and **S**pace **A**dministration
IR	**I**nfra**r**ed
PMT	**P**hoto **M**ultiplier **T**ube
UK	**U**nited **K**ingdom

Physical Constants

Speed of Light	$c_0 = 2.997\,924\,58 \times 10^8\,\mathrm{m\,s^{-1}}$ (exact)
Diameter of Sun	$D_S = 1.391000 \times 10^6 km$
Distance from Earth to Sun	$AU = 1.496 \times 10^6$

List of Symbols

a	distance	m
P	power	W (J s^{-1})
Ω	Solid Angle	Steradians
L_B	Effective Radiance	$\frac{\mathrm{W}}{\mathrm{cm}^2\mathrm{sr}}$
E_B	Effective Irradiance	$\frac{\mathrm{W}}{\mathrm{cm}^2}$
L_λ	Spectral Irradiance	$\frac{\mathrm{W}}{\mathrm{cm}^2\mathrm{sr}\cdot\mathrm{nm}}$
$B(\lambda)$	Blue-Light Hazard Function	Unitless
t	Time	seconds
α	Angular Subtense	Radians
λ	Wavelength nm	
ω	angular frequency	rad

Dedicated to my wife Natasha & children Benjamin, Shiloh, Griffin, Archer

Chapter 1

Background information and theory

1.1 Minimum OD Calculation

This research uses a minimum calculated Optical Density (OD) of 4.5 for wavelengths 380-780 nm. The following section shows the full calculation of this minimum OD for a broadband source used to arrive at such criteria.

The Sun can be a source of many different types of hazards including;

- Broadband UV (Cornea)
- UV-A (lens + retina)
- Retina (Thermal)
- Retina (Photochemical) - "blue light"
- IR (cornea)
- Visible - IR hazard skin
- Retinal Thermal IR for really dim sources

The two that pose the most hazards during an eclipse would be Retina (Photochemical) and Retina (Thermal). Retina (Photochemical) will be the only hazard analyzed in this section.

The data in Figure 1.1 comes from an extremely accurate computer model of the Spectral Irradiance of the Sun. The parameters are as follows

- Spectral optical depth of aerosol extinction at 500 nm
- Ground Reflection: 0.2
- Air Mass: 1
- Water Vapor Column (WVC): 1.42
- Total Column Ozone (Oz): 0.34
  - Miliatmospheric measured in centimeters
- Spectral Optical Depth of Aerosols (Sp Opt Depth) 0.1

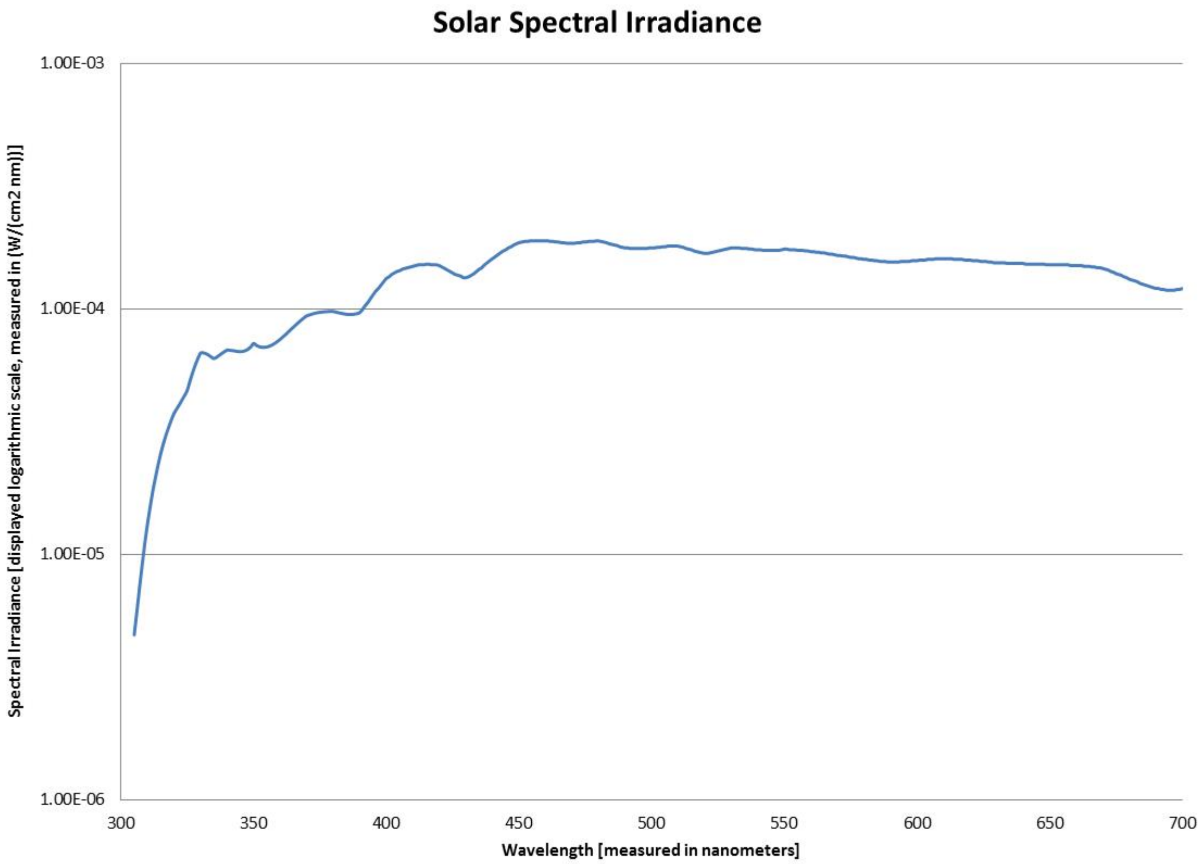

FIGURE 1.1: Solar Spectral Irradiance Data for the Sun at normal incidence to a flat surface

The vertical axis is the modeled Spectral Irradiance as measured in $\frac{\mathrm{W}}{\mathrm{cm}^2\mathrm{nm}}$, and the horizontal axis is the corresponding wavelength as measured in nanometers. The data shows the spectral irradiance of the Sun as it shines at normal incidence (close to mid-day) and hits a flat surface. Seven other spectral lines were provided to model different parameters however, this particular setting proved to be the most hazardous. With respect to "Worst Case Scenario" this is the only data set analyzed (Trial 8) in this section. The other parameters that were discarded because they did not yield the most hazardous (highest) spectral irradiance were

Name→	Trial 1	Trial 2	Trial 3	Trial 4
Altitude	Sea Level	Sea Level	Sea Level	Sea Level
Ground Reflection	0	0	0.2	
Air Mass:	1	1	1	1
WVC:	1.42	1.42	1.42	2
Oz:	0.34	0.27	0.27	0.3
Sp opt depth	0.1	0.1	0.1	0.2

Name→	Trial 5	Trial 6	Trial 7	Trial 8
Altitude	Sea Level	Sea Level	Sea Level	Sea Level
Ground Reflection				0.2
Air Mass:	1.5	2	5.6	1
WVC:	2	2	2	1.42
Oz:	0.3	0.3	0.3	0.34
Sp opt depth	0.2	0.2	0.2	0.1

1.1.1 Retina (Photochemical) "Blue Light" Hazard Calculations

Of all the hazards that the Sun presents during the eclipse one of the greatest concerns is the Retina (Photochemical) or "Blue light" hazard. This section will only analyze the blue light hazard. Retina Thermal hazards happen over very short durations, whereas Photochemical hazards happen over long durations. Solar injuries happen over long durations (longer than 10 s). All historical solar injuries have been attributed to the Photochemical "Blue light" hazard.

Effective Radiance of Light Source, L_B

The effective radiance of a light source[1], L_B is measured in $\frac{\mathrm{W}}{\mathrm{cm^2 sr}}$. The L_B can be found by integrating the spectral irradiance L_λ, as measured in $\frac{\mathrm{W}}{\mathrm{cm^2 sr \cdot nm}}$, weighted by the blue-light hazard function $B(\lambda)$. There are a number of weighting functions that are defined in Table 2 of the Light and Near-Infrared Radiation document published by ACGIH 2015 including Aphakic Hazard Function $A(\lambda)$, Retinal Thermal Hazard Function $R(\lambda)$, and Blue-Light Hazard Function $B(\lambda)$. The Blue-light hazard function is being used for this part of the evaluation because it is the particular hazard that this section is evaluating. The equation for the effective radiance L_B is

$$L_B \left[\frac{\mathrm{W}}{\mathrm{cm}^2 \cdot \mathrm{sr}}\right] = \sum_{305}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \frac{\mathrm{W}}{\mathrm{cm}^2 \cdot \mathrm{sr}} \tag{1.1}$$

The Blue-light Hazard Spectral Weighting Function, $B(\lambda)$ values[2] can be combined with the spectral irradiance to get a weighted effective irradiance, as shown in Figure 1.2.

The integration of the weighted effective irradiance (Figure 1.2) yields

$$L_{\text{effective } B}\left[\frac{\mathrm{W}}{\mathrm{cm}^2}\right] = E_B = 1.131 \times 10^{-2} \frac{\mathrm{W}}{\mathrm{cm}^2} \tag{1.2}$$

Full Radiance, L_B and Solid Angle, Ω

To get the full effective radiance of a light source L_B we need to divide this number by the solid angle of the Sun.

The solid angle of the Sun is a measure of how large the Sun appears to an observer looking from Earth.

$$\text{Solid Angle} = \frac{\text{Flat Disk Area Area presented by the Sun} = \frac{\pi D^2}{4}}{(\text{Earth-Sun Distance})^2}$$

[1] Eqn 1, pg 3 from Light and Near-Infrared Radiation ACGIH 2015
[2] Table 2, pg 4 from Light and Near-Infrared Radiation ACGIH 2015

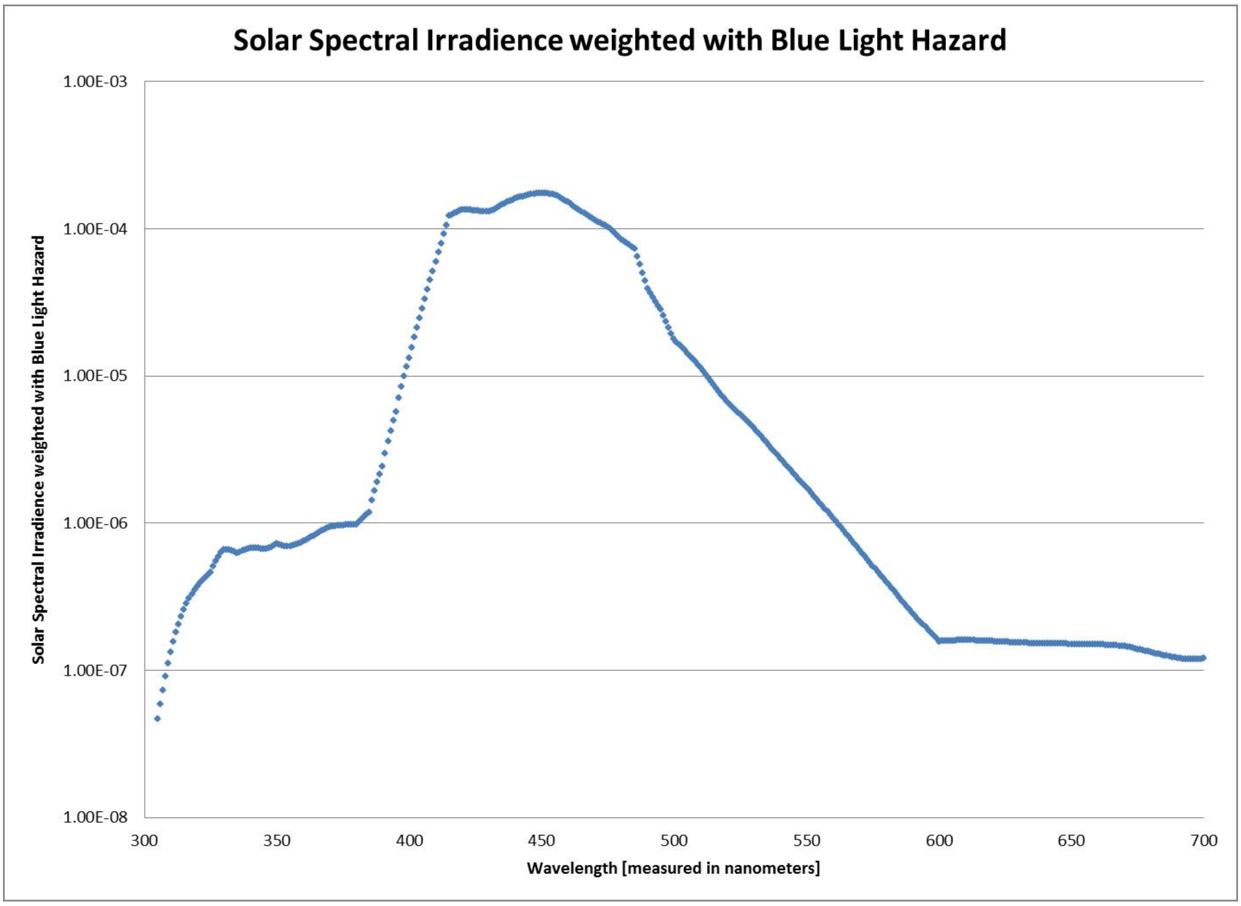

FIGURE 1.2: Solar Spectral Irradiance weighted with the values for Blue Light Hazard

$$\begin{aligned} \Omega &= \frac{\frac{\pi(1.3914\times10^{6}\text{km})^2}{4}}{(1.496\times10^{8}\text{km})^2} \\ &= 6.794\times10^{-5}\text{sr} \end{aligned}$$

$$L_B\left[\frac{\text{W}}{\text{cm}^2\cdot\text{sr}}\right] = \frac{1.131\times10^{-2}}{6.794\times10^{-5}} \tag{1.3}$$

$$= 1.665\times10^{2}\frac{\text{W}}{\text{cm}^2\cdot\text{sr}} \tag{1.4}$$

Comparing our L_B to exposure limits

The acceptable exposure limit for viewing durations greater than 10^4 s is[3]

$$L_B\left[\frac{\text{W}}{\text{cm}^2\text{sr}}\right] = 10^{-2}\frac{\text{W}}{\text{cm}^2\text{sr}} \tag{1.5}$$

which is much smaller than the calculated exposure.

[3]Eqn 2c, pg 3 from Light and Near-Infrared Radiation ACGIH 2015

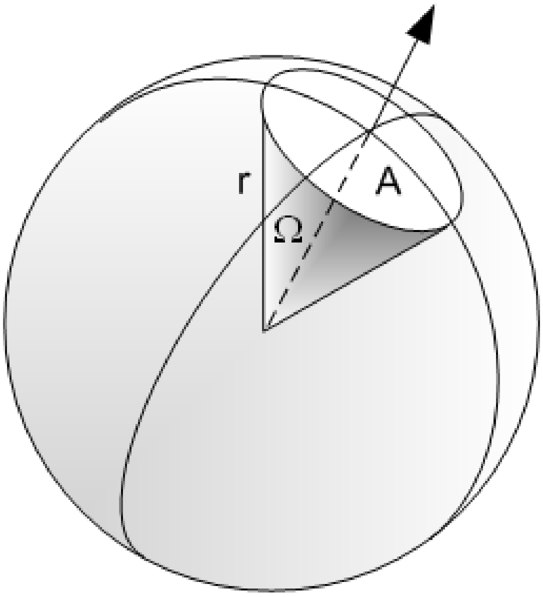

FIGURE 1.3: Diagram for Solid Angle

For cumulative viewing durations, t less than 10^4 s within a day the acceptable exposure[4] is

$$L_B\left[\frac{\mathrm{W}}{\mathrm{cm}^2\mathrm{sr}}\right] \leq \frac{100}{t} \tag{1.6}$$

Solving for t

$$t \leq \frac{100}{L_B} \tag{1.7}$$
$$\leq 6.007 \times 10^{-1}\ \mathrm{s} \tag{1.8}$$

This says that if one cumulatively look up at the Sun for just over half a second they will exceed the limit.

Calculating the Optical Density required

The equation for Optical Density is a logarithmic ratio of the falling radiation to the transmitted radiation through a material.

$$\mathrm{OD}_{\text{large source}} = \log_{10}\left(\frac{1.665 \times 10^2}{10^{-2}}\right) \tag{1.9}$$
$$= 4.221 \tag{1.10}$$

For the most part, manufacturers do not produce optical densities to this precision so this OD must have been rounded up to 4.5. This number is one of the criteria used in this research and is also confirmed directly in publications from NASA[5].

[4] Eqn 2a, pg 3 from Light and Near-Infrared Radiation ACGIH 2015
[5] NASA RP 1383 Total Solar Eclipse of 1999 August 11, April 1997, p. 20

1.1.2 Other Parameters

Retinal (Thermal) Hazard

The Retinal (Thermal) Hazard calculations involves the same procedures presented in the previous section applied to the Spectral Radiance of the Sun from 780-1400 nm. This data was not readily available so the recommendations from NASA[6] was used. From 780-1400 nm a minimum OD of 2.3 is recommended.

Maximum OD for Viewing at Visible Wavelengths

A maximum OD of 6.2 was set for wavelengths between 380-1400 nm. This comes from recommendations by NASA[7]. While glasses that had an OD above 6.2 would provide more than enough protection, it would transmit so little light that it would be very difficult to see an eclipse event through such glasses.

1.1.3 Special Case for Small Angle

There is a special case[8] that is worth mentioning for small source angles subtending an angle less than 0.011 radian. This special case was not used in the research but the calculations are presented in this section to show that this research considered such a possibility. If the subtended angle is less than 0.011 radians the acceptable exposure limit can be relaxed. At this point we need to calculate the "Angular Subtense," which is the angle that ones eyes sweep as it scans from the opposite edges of the Sun (See Figure 1.4). The calculation for the angle will only take into account the

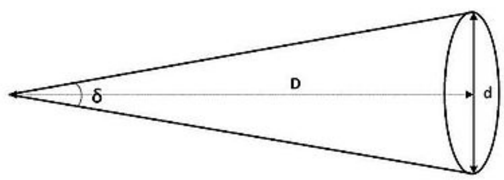

FIGURE 1.4: Diagram for Angular Subtense of Sun

ratio between the diameter of the Sun and the distance from the earth to the Sun, because of the small angle approximation.

$$\text{Angular Subtense} = \frac{\text{Sun's Diameter}}{\text{Earth-Sun Distance}} \tag{1.11}$$

$$\alpha = \frac{1.3914 \times 10^6 \text{ km}}{1.496 \times 10^8 \text{ km}} \tag{1.12}$$

$$= 0.009301\text{rad} \tag{1.13}$$

$$= 9.301 \times 10^{-3}\text{rad} \tag{1.14}$$

$$= 9.301\text{mrad} \tag{1.15}$$

This angle is smaller than the limit for the special case, $0.009301 < 0.011$ so we meet the criteria. Because we meet the blue light small source criteria we can evaluate according the the relaxed safety limit. The course of the total eclipse is going to

[6]NASA RP 1383 Total Solar Eclipse of 1999 August 11, April 1997, p. 20
[7]NASA RP 1383 Total Solar Eclipse of 1999 August 11, April 1997, p. 20
[8]Eqn 3, pg 3 from Light and Near-Infrared Radiation ACGIH 2015

be about two minutes long. However this analysis will assume that people will be looking at the Sun for some time before and after the total eclipse. Since the viewing durations will most likely be greater than 10^2 s in a day, the weighted irradiance[9] E_B is

$$E_B \left[\frac{\mathrm{W}}{\mathrm{cm}^2}\right] \leq 10^{-4}\frac{\mathrm{W}}{\mathrm{cm}^2} \quad (1.16)$$

$$E_B = L_B \left[\frac{\mathrm{W}}{\mathrm{cm}^2\mathrm{sr}}\right] \Omega\,[\mathrm{sr}] \leq 10^{-4} \quad (1.17)$$

$$1.131 \times 10^{-2}\frac{\mathrm{W}}{\mathrm{cm}^2} \leq 10^{-4}\frac{\mathrm{W}}{\mathrm{cm}^2} \quad (1.18)$$

which is FALSE. All we have proved at this point is that even with the small source special case we cannot look at the Sun without going over the limit.

$$\mathrm{OD} = \log_{10}\left(\frac{I_0}{I}\right) \quad (1.19)$$

Applying our small source limit parameters of $E_{B0} = 1.131 \times 10^{-2}\left[\frac{\mathrm{W}}{\mathrm{cm}^2}\right]$, and $E_B = 10^{-4}\left[\frac{\mathrm{W}}{\mathrm{cm}^2}\right]$ we get

$$\mathrm{OD}_{\text{small source}} = \log_{10}\left(\frac{1.131 \times 10^{-2}}{10^{-4}}\right) \quad (1.20)$$

$$= 2.053 \quad (1.21)$$

Which seems quite low, especially considering NASA recommends an OD of 4.5 at this wavelength range. This research has decided on an OD of 4.5 as the minimum protection required for 380-780 nm to take the more conservative approach. Additional this number keeps this research consistent with NASA.

1.2 Information from Tri-Fold Brochure

The following Tri-fold brochure is in the process of being published in a nationally distributed newsletter. It is written for the general population, so that it will be accessible to people who know very little about the upcoming eclipse and the safety precautions required for proper viewing.

1.2.1 Introduction

In preparation for the upcoming American solar eclipse occurring on August 21, 2017 many people have inquired about what is considered "safe" when purchasing "Eclipse Glasses." Choosing the wrong eye protection could lead to permanent damage to the retina. There are many on the market that claim to be safe, however there are some that are not safe and could lead to eye damage despite the manufacturer's claims. There are distinguishing markings or certifications that manufacturers will put on their glasses or advertise with their glasses. Some of these include ISO 12312-2, CE, and ANSI Z87. Most people do not know what these markings mean and how they apply to solar eye protection. This brochure will explain what some of

[9]Eqn 4c, pg 3 from Light and Near-Infrared Radiation ACGIH 2015

these markings are and show you data to help you choose the safest eye protection to use for viewing an eclipse.

1.2.2 How to read this graph and pictures

- See Figure 1.5
- Optical Density (OD) is related to how well the glasses will protect your eyes. The higher the OD (the vertical scale) the more protection provided.
- The red shaded area in graph marked "Caution" shows a region where the OD will be insufficient to provide adequate protection against eye injuries. This region is based on numbers provided by NASA.
- The grey shaded area marked "Attention" shows a region in which it would be too dark to see through. While this would provide adequate protection, it will be too dark to see an eclipse.
- The four pictures (Figures 1.6- 1.9) show what a 100 W incandescent light bulb looks like through filters for comparison sake.

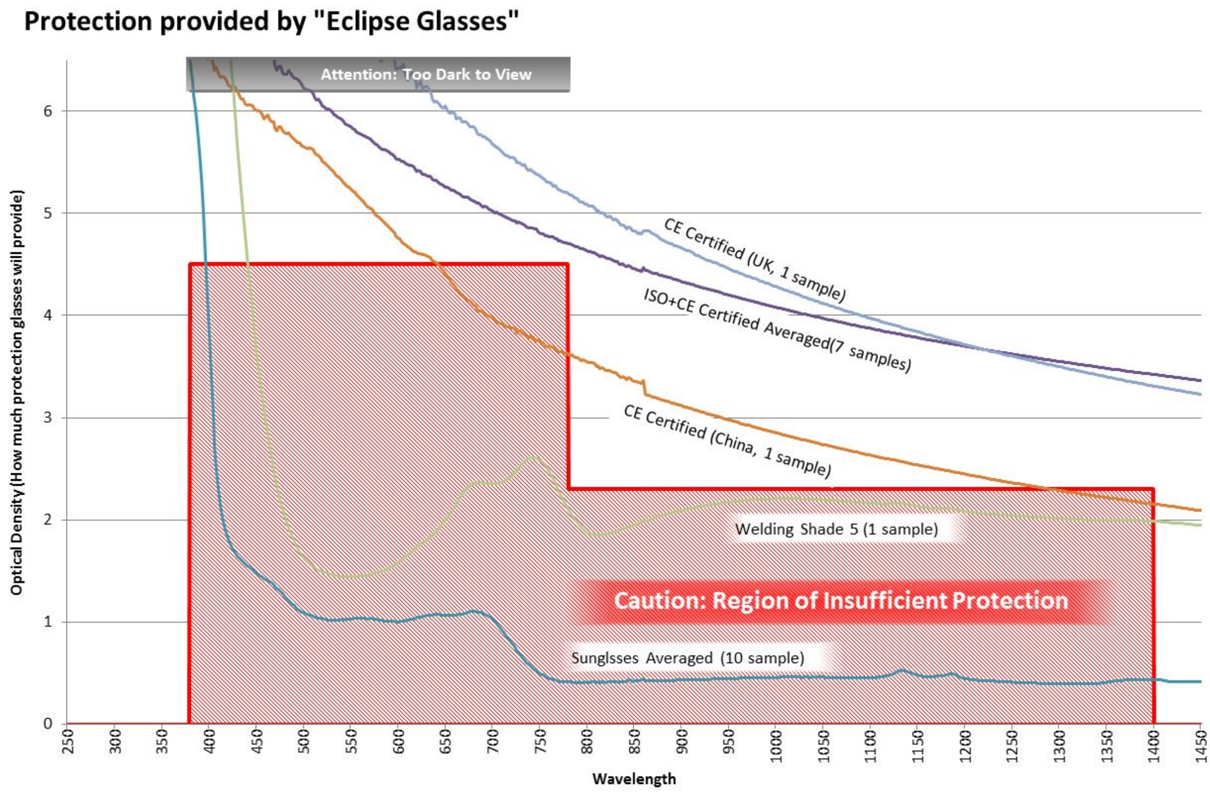

FIGURE 1.5: Summarized Eclipse Glasses Data

1.2.3 Analysis

Which glasses tested were considered safe for viewing an eclipse?

- "ISO+CE Certified Averaged" data above is the average of seven different glasses tested that have both the ISO 12312-2 and CE markings. **All glasses with ISO and CE certifications tested are considered safe**, with no part falling inside of the red shaded area. See Figure 1.6.

Which glasses may or may not be considered safe for viewing an eclipse?

- "CE Certified (China)" data is from one pair of glasses that only had CE certification and is manufactured in China. These glasses do not meet the recommended minimum OD for wavelengths 644-780 nm and 1284-1400 nm. See Figure 1.7.

- "CE Certified (UK)" data is from one pair of glasses that only had CE certification and are designed and tested in the UK. Glasses meet the recommended minimum OD for all wavelengths (stays outside the red shaded area) however they may filter out too much of the eclipse to see the event clearly as they would only allow some of the orange and red wavelengths through. This point is illustrated in Figure 1.8.

What type of glasses tested is NOT considered safe for viewing an eclipse?

- "Welding Glass Shade 5" data is from welders goggles of shade 5, and does not meet the minimum OD requirements for wavelengths 425-1400 nm. If you search for "Eclipse Glasses" to purchase online, 5% of these will be welding glass shade 5. NASA recommends Shade 14 for safe eclipse viewing.

- "Sunglasses Averaged" is averaged data from ten different commercially available Sunglasses. Some markings may include CE or ANSI Z87. All Sunglasses tested fell well below the recommended minimum OD. See Figure 1.9, these specific glasses are given a name like "Eclipse Safety Glasses."

1.2.4 Conclusions

- All glasses that are ISO and CE certified will provide minimum recommended protection required to view the eclipse safely.

- Some glasses that only have generic CE markings do not meet the minimum protection.

- If using welding glass a Shade 14 (tested but not shown in the graph) will provide sufficient eye protection. Shade 5 does not meet the recommended minimum OD.

- **Virtually all commercially available Sun glasses will not protect your eyes when viewing an eclipse**, as they were not designed for directly viewing the Sun. Wearing multiple pairs (which was also tested) will not provide sufficient protection.

FIGURE 1.6: 100W ISO+CE

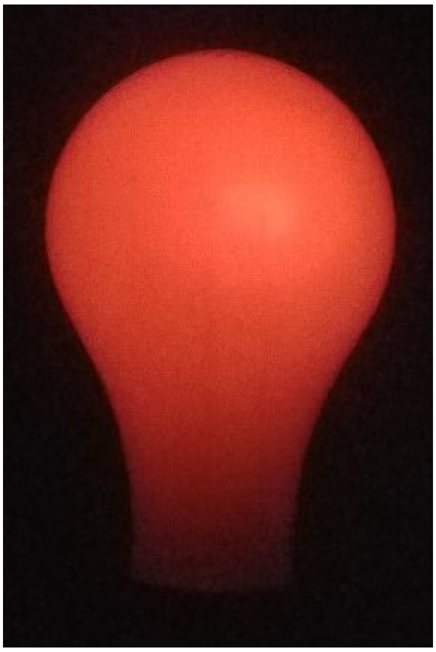

FIGURE 1.7: 100 W through China CE

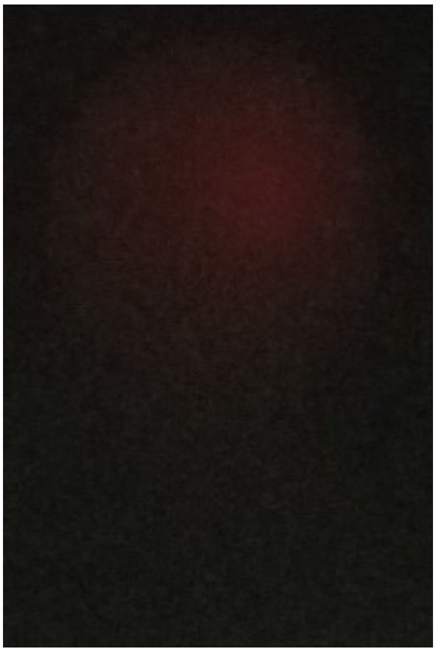

FIGURE 1.8: 100W through UK CE

FIGURE 1.9: 100W through Non-certified glasses

1.2.5 Definitions and Interesting Points

- 12312-2 Certified is an international certification which talks specifically about viewing solar eclipses.
- Certified stands for "Conformité Européene" which translates to "European Conformity." This marking is most likely found on electronics, toys, medical devices, radios, phones, etc...
- ANSI Z87.1 is a standard that is related to blunt impact, radiation, dust, splashes and droplets. It is not related to viewing a solar eclipse directly.

1.2.6 Technical Details of Research

- Caution Region, red region indicated in graph
  - Min OD of 4.5 at 380-780 nm
  - Min OD of 2.3 at 780-1400 nm
- Attention Region, orange region indicated in graph
  - Max OD of 6.2 at 380-780 nm
- ISO+CE Averaged exceeded OD of 6.2 at 506 nm and below, cutting out violet, indigo, blue, and some green wavelengths.
- CE (UK) glasses exceeded an OD of 6.2 at 632 nm and below, allowing only red and some orange wavelengths through.
- Black polymer filters tend to render the Sun as a yellow disk, while aluminized polyester (mylar) gives a blue-white image.
- Pictures of 100 W light bulbs taken at 25 cm. Images taken by author. These images are shown to help compare the different filters.

Chapter 2

Experimental Setup

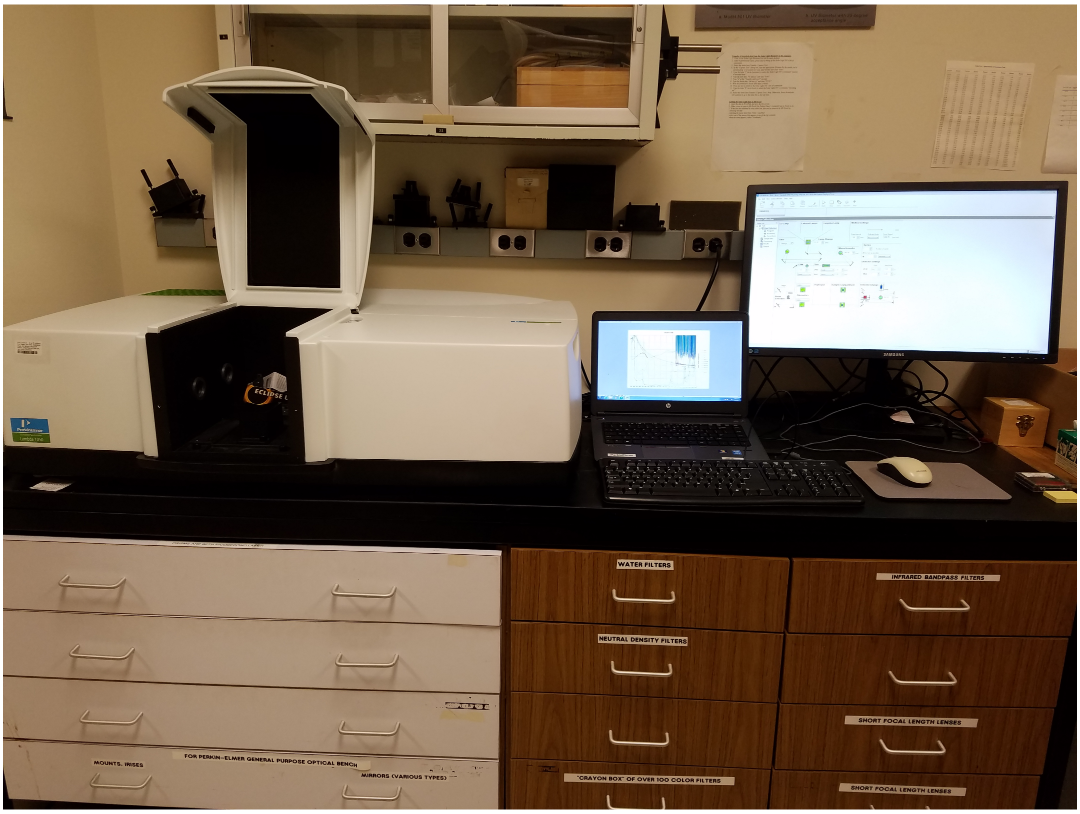

FIGURE 2.1: Full lab set up

Figure 2.1 shows the full lab configuration used for this research. On the left is the Perkin Elmer Lambda 1050 device, with the access door open and sample glasses in place. The computer on the right has the WinLab software used to analyze the data and configure the Spectrometer.

2.1 Research Setup and Background Info

“None” is an interesting category. These glasses come up when one types in “eclipse glasses” into an internet search (which would lead people to think that they may be safe to view the eclipse with). Some of these glasses were even given a name like “Eclipse Safety Glasses.” Warning: this does not mean that these safety glasses are safe for viewing an eclipse. These are just safety glasses given the name “Eclipse.”

OD is kind of a measurement of how "dark" a particular eye protection is. Basically, the higher the number, the greater protection it will provide for that specific wavelength. Any pair of eye protection, will not have the same OD for all wavelengths. So the graph shows the OD of different types of eye protection for the specific wavelengths. For a solar eclipse, a minimum OD of 4.5 is required for wavelengths between 380-780 nm, and minimum OD of 2.3 is required for wavelengths between 780-1400 nm to provide sufficient protection, which is designated in the graphs (Figures 3.1 - 3.4) as the red "Reference Min" shaded area. Keep in mind that there are safety factors built into this. There is also an upper gray shaded area in the 380-780 nm range which is a maximum OD. While eye protection that is above this line would be deemed safe to view a solar eclipse with, it would be very difficult if not impossible to actually see anything with glasses that are this dark. It's fine, if part of the data goes above this line, it just means that one will not be able to see certain colors when viewing an eclipse.

The presented scans were done on a PerkinElmer Lambda 1050 device, with a sample taken every 2 nm. Additional data for Welding and Safety glasses was provided by ICS labs. "ISO+CE" means that the glasses were both ISO 12312.2 and CE certified. They all happened to be manufactured by American companies. "CE" means that the glasses only had a CE marking on them, one pair of glasses tested was manufactured in Europe and the other in China. "None" is the category reserved for what can best be described as safety glasses which came up when searching for "Eclipse glasses." "Weld" means that the glass was used for welding purposes, and the numbering convention is a little different as they are numbered according to the shade number that is associated with them.

An OD over 7 is transmitting less than 0.0000001% of light and is extremely difficult for any detector to accurately measure. Additionally, an OD over 7 is well above any requirements for eye protection in a solar eclipse so there's really no need in showing data with such a high OD rating. For this reason if the graph showed an OD greater than 7, we assumed it is equal to 7.

2.2 Technical Configurations

For this research a UV/VIS/NIR Spectrometer Lambda 1050 device manufactured by Perkin Elmer, was used. The spectrometer uses a PMT detector for wavelengths below 860 nm, and InGaAs detector for wavelengths between 860 nm and 1800.80 nm, and a PbS detector for wavelengths greater than 1800.80 nm. Being that by nature these glasses have an extremely high OD, the measurement is difficult, particularly in the 250 to 350 nm UV range. For this reason the reference beam was given a 0.1% attenuation factor in order to minimize the ratio between the reference beam and the sample beam (See Figure 2.3). The PMT was set to have a fixed slit width of 5.00 nm and the InGaAs and PbS detectors had a variable slit width operated by a servo motor. Data was collected every 2.00 nm, however, the response time was increased, so the detector would dwell on a sample for 0.32 s for every data point. The PMT was set to an auto gain, the InGaAs had a gain of 7.00, and the PbS did not have any additional gain. The detector was run in this configuration between 250 and 2000 nm.

When the spectrometer switched over to use the PbS detector the data went too far in the other direction, and zeroed out a lot of the data above 1800 nm, because the

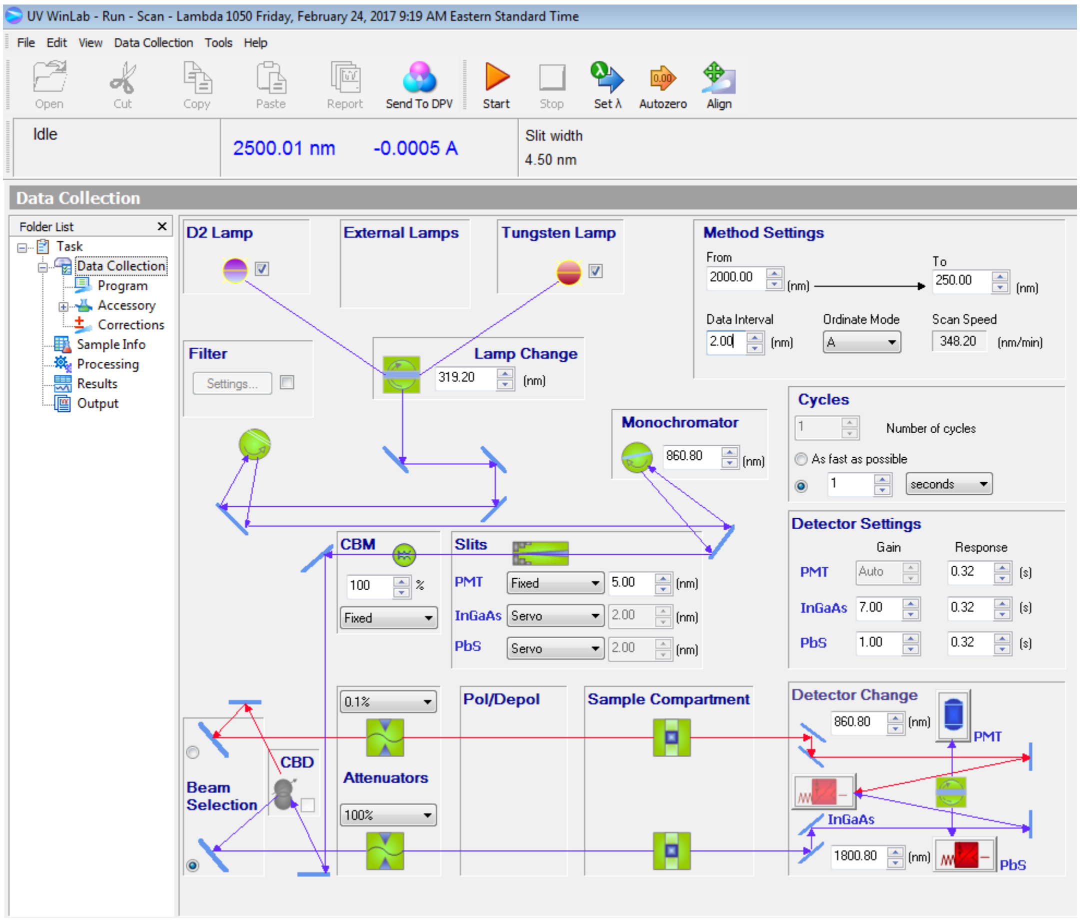

FIGURE 2.2: Software settings for Lambda 1050 device to scan 250-2000 nm

attenuation factor on the reference beam must have been too high. All of the samples were re-run at a 100% of the reference beam from 1810 to 2500 nm, while keeping all the other settings the same. The data presented in a splice of these two data sets are: 250 to 1800 nm having a 0.1% reference beam, and 1810-2500 nm having a 100% reference beam. This accounts for the small gap in the data between 1800 and 1810 nm.

As will be seen in the data in the following chapter, there is a small spike in the all of the data at 860 nm. This is because the spectrometer is switching from an InGaAs detector to a PMT detector. Additionally, by the nature of the detector there is a lot more noise associated with the PMT and PbS detectors. This can be seen by observing how smooth the InGaAs data seems to be as compared to the other detectors. After letting the lamp warm up for an hour, all data was taken with the same calibration, on the same day, in an effort to control outside variables.

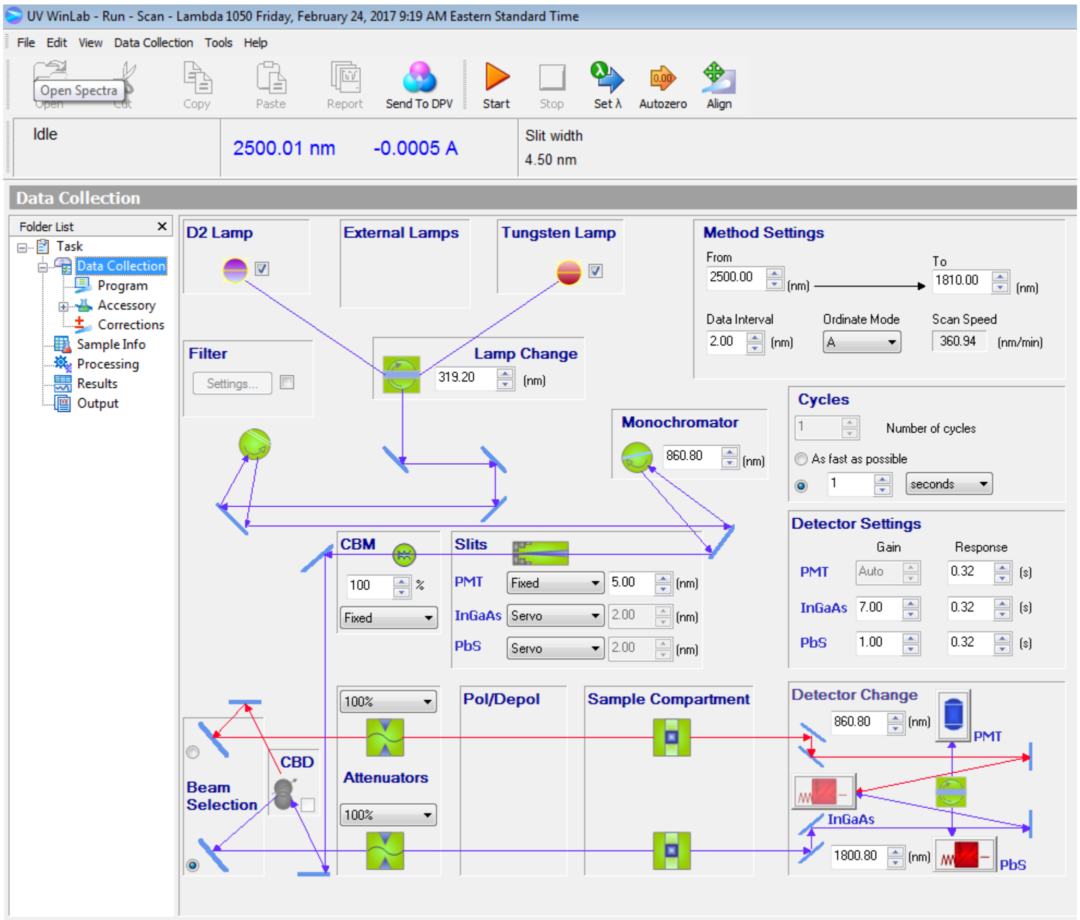

FIGURE 2.3: Software settings for Lambda 1050 device to scan 1810-2500 nm

Chapter 3

Data and Analysis

3.1 ISO+CE Certified

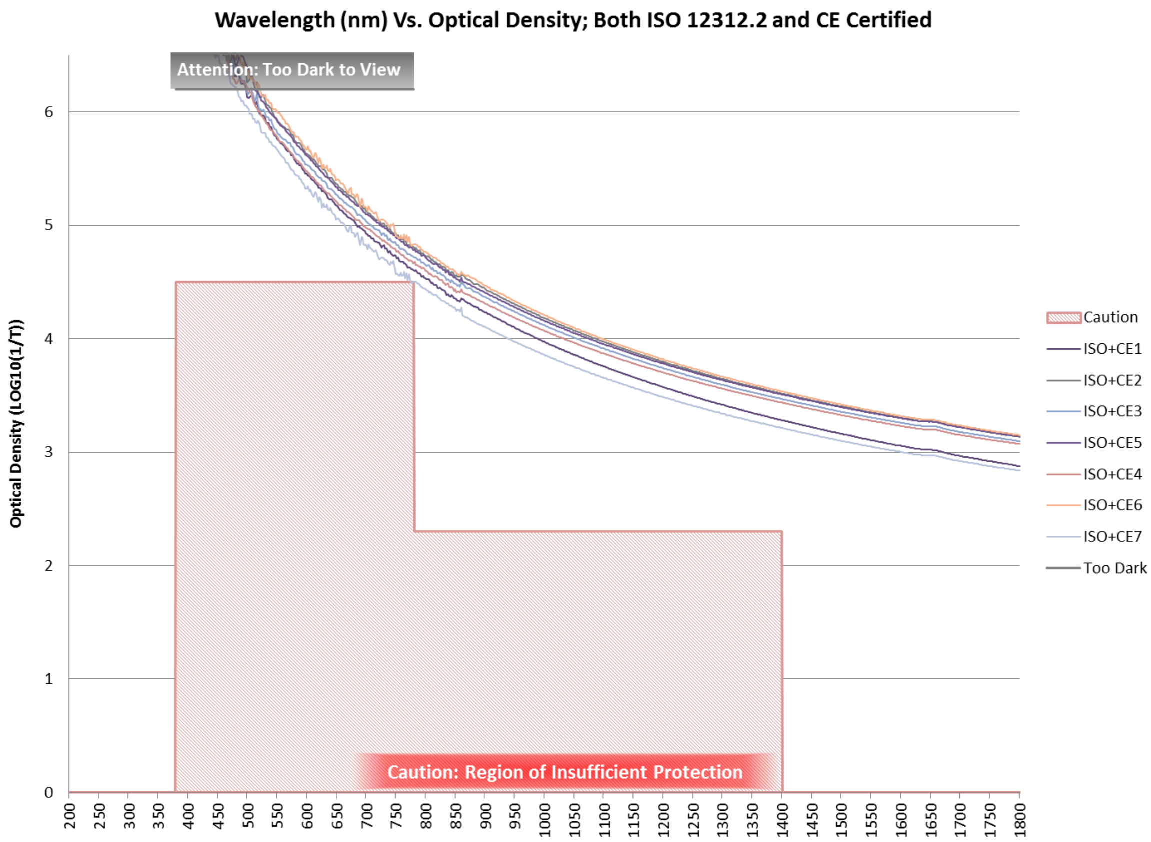

FIGURE 3.1: OD vs. λ data for ISO+CE Certified Glasses

The OD for glasses that conform to the ISO certification are above the red reference line at all wavelengths (see Figure 3.1). All ISO certified glasses tested also had CE certification. The average for these glasses goes above an OD of 6.2 at 506 nm and below. This means that the violet, indigo, blue, and some of the green wavelengths of the Sun will be very hard to see. To date, the author could only find three manufacturers that are ISO 12312.2 Certified. These manufacturers offer their glasses to many brands of glasses, which means that the vast majority (if not all) glasses that claim to have ISO certification are made with lenses provided from these three manufactures in America.

3.2 CE Certified

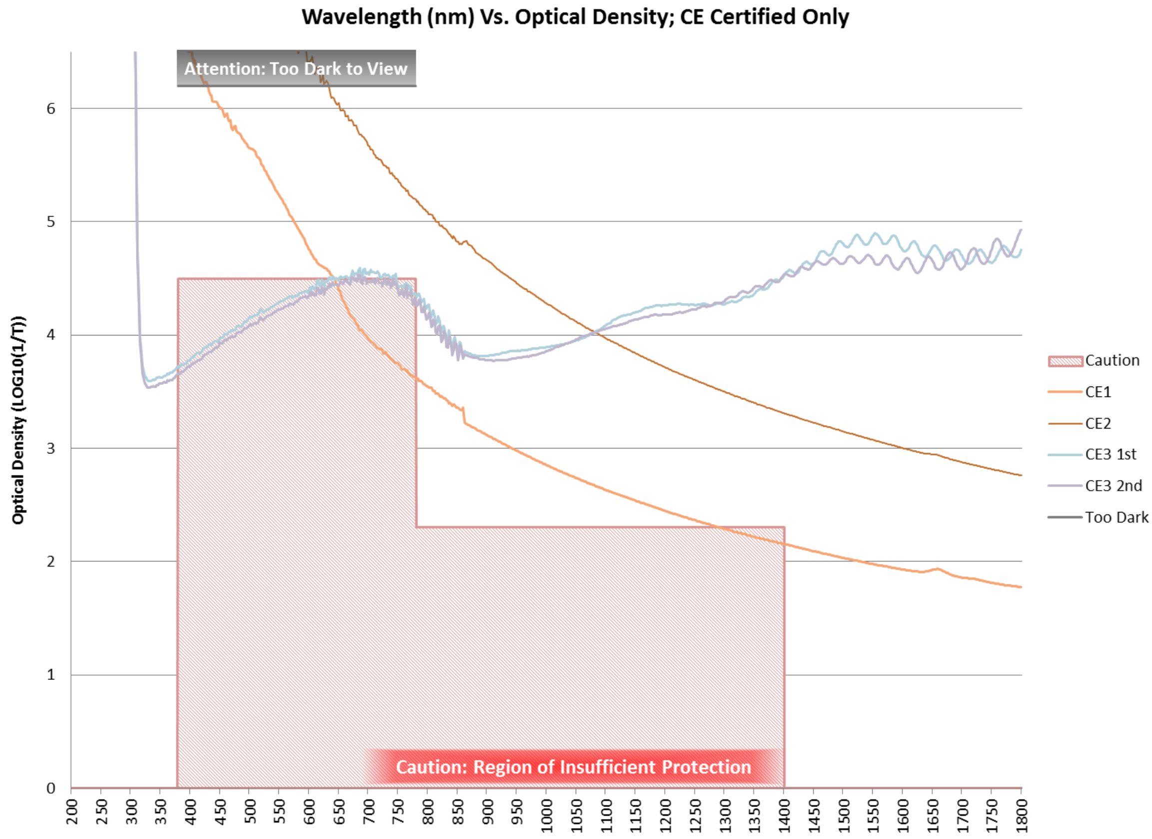

FIGURE 3.2: OD vs. λ data for CE Certified Glasses.

There are a few glasses that were tested that only had a CE certification. All glasses tested that only had this marking happened to be manufactured by a company in either the UK or China. It cannot be said that if one uses glasses that are only CE certified they will be susceptible to eye injuries. However of the three CE only glasses that were tested, only one was above the minimum OD requirements. There is a lot of variation in these glasses even though they all have a CE certification.

- The glasses labeled CE1 represented by the bold orange line are the first glasses that come up when the term "eclipse glasses" was searched in a popular online retail site. These glasses fall below the minimum recommended OD requirements within the wavelengths of 644-780 nm and 1294-1400 nm.

- The glasses labeled CE3 are eclipse glasses were originally featured in an eclipse article written in 1999, and found in a cabinet in the Nonionizing Radiation Division laboratory at Aberdeen Proving Ground. This suggests that they must have made these types of glasses using different material 17 years ago than the ones that are used now. Also these eclipse glasses are made to be disposable and should only be used for the eclipse they were designed for.

- Even the CE2 glasses may not be favorable. Indeed, they are well above the red reference line, however they go above an OD of 6.2 from 632 nm and below. This means that one won't be able to see the solar eclipse as well as the ISO certified glasses. This also means that in addition to the violet, indigo, blue, and green wavelengths, the yellow and orange wavelengths will also be cut out.

3.3 Welding Glass

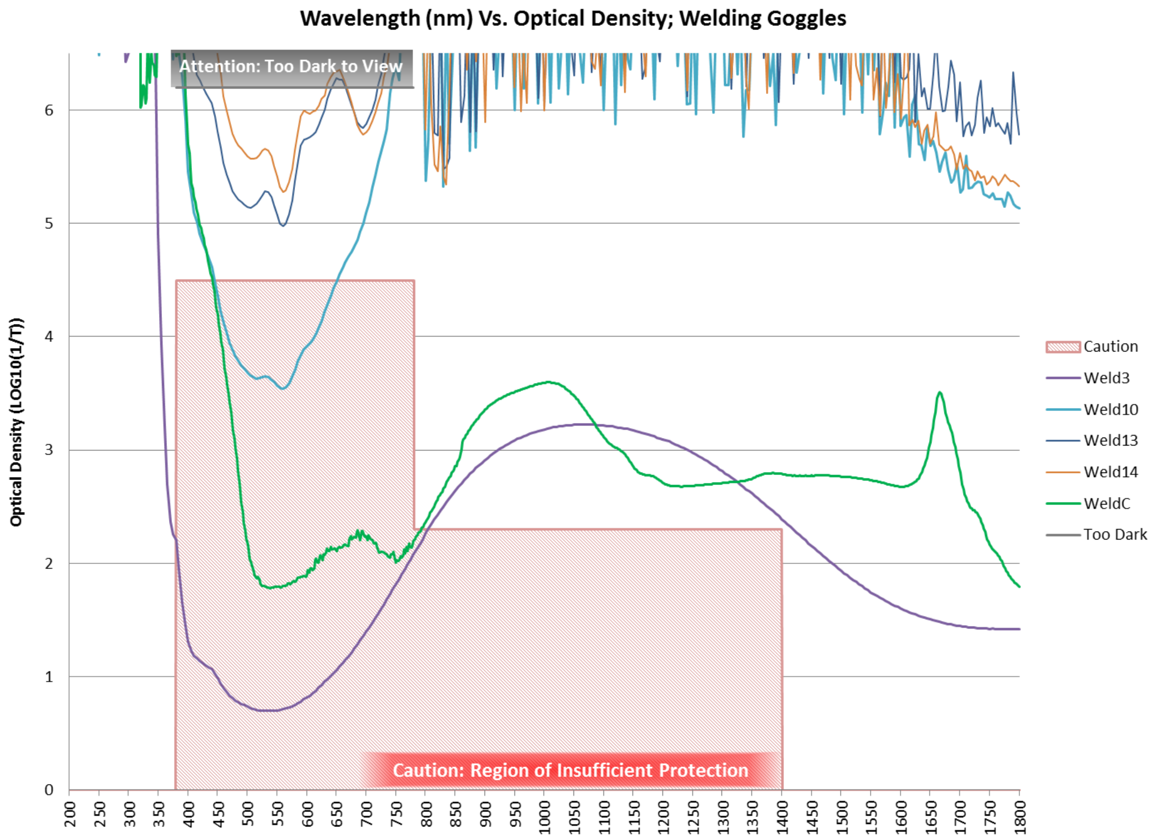

FIGURE 3.3: OD vs. λ data for Welding Glass

Most shades of welding goggles do not provide sufficient protection. Shade 3 and Shade 10 may provide some protection in the IR and UV portion of the spectrum. They provide insufficient protection in the visible portion of the spectrum. Of the data presented, Shade 13 and Shade 14 do in fact provide sufficient protection, and references from private communications confirm that Shade 12 also will have a high enough OD, although Shade 14 is recommended. The reason for this is that even though Shade 12 and 13 do provide the minimum protection, looking at an eclipse event through these may prove to be uncomfortable. The research also scanned a pair of Welding Cutting goggles designated WeldC in the graph above, in the visible portion of the spectrum these fall below the red reference line.

Operation	Electrode Size	OSHA Min. Shade #
Shielded Metal Arc Welding	$> \frac{1}{4}$ in.	11

TABLE 3.1: OSHA Minimum Protective Shade Requirements for filter lenses for protection during Shielded Metal Arc Welding.

Operation	Plate Thickness	OSHA Min. Shade #
Gas Welding	$> \frac{1}{2}$ in.	6
Oxygen Cutting	> 6 in.	5

TABLE 3.2: OSHA Minimum Protective Shade Requirements for filter lenses for Gas Welding and Oxygen Cutting Operations.

According to the Occupational Safety and Health Administration, vast majority of the different types of welding do not require a protective shade number as high as 14 (as shown in Tables 3.1- 3.3)

Operation	Arc Current (Amperes)	OSHA Min. Shade #
Gas Metal Arc Welding	$> 250 - 500$ A	10
Flux Cored Arc Welding	$> 250 - 500$ A	10
Gas Tungsten Arc Welding	$> 150 - 500$ A	10
Air Carbon Arc Cutting	$500 - 1000$ A	11
Plasma Arc Welding	$> 400 - 800$ A	11
Plasma Arc Cutting	$> 400 - 800$ A	10
Torch Brazing		3
Torch Soldering		2
Carbon Arc Welding		14

TABLE 3.3: OSHA Minimum Protective Shade Requirements.

3.4 Non-Certified Glass

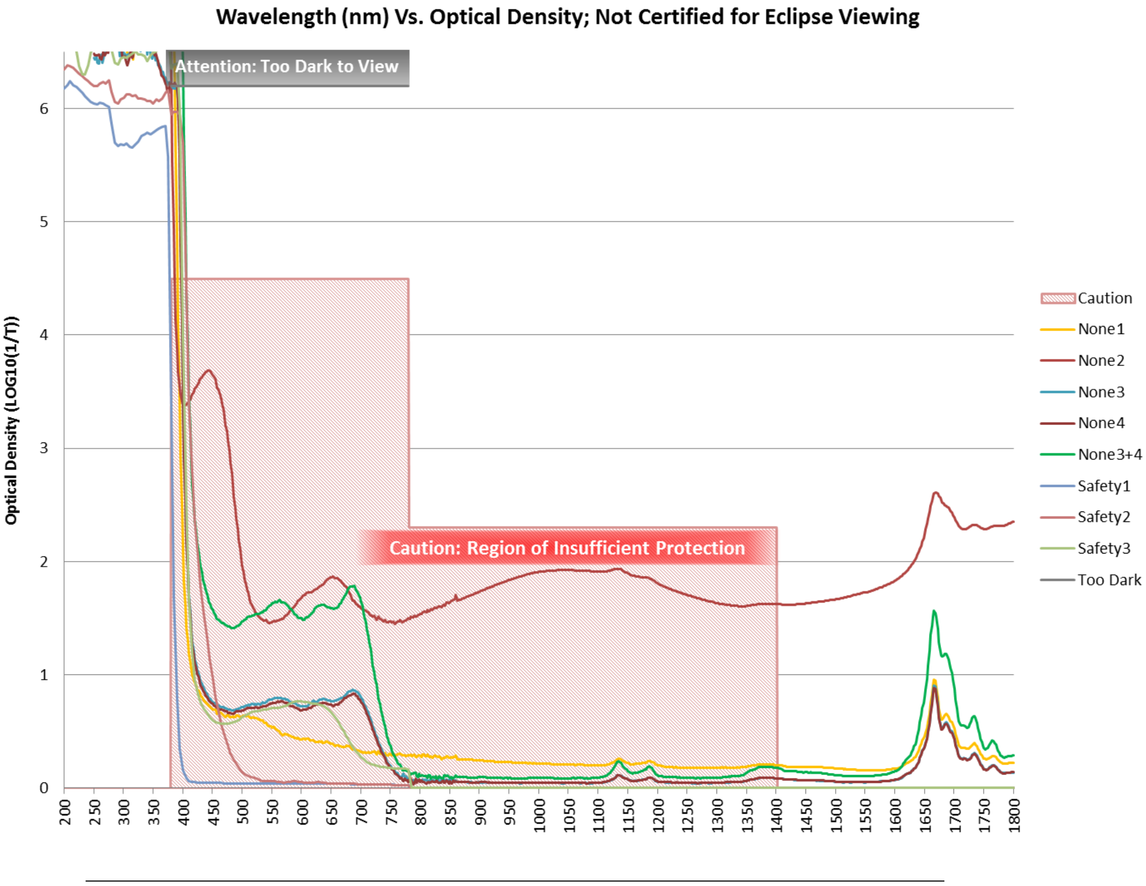

FIGURE 3.4: OD vs. λ data for Non-Certified Glasses

The data lines labeled "None" are offered as options when one shops for "eclipse glasses" online. These are not advertised as safe to view an eclipse with, even though they are given names like "Eclipse Safety Glasses" (see the orange data line in the graph above). The glasses in the "None" category came from two independent companies. They both advertise that their glasses meets/exceed ANSI Z87.1 standards. While this may be true, ANSI Z87.1 is the American National Standards Institute code for dealing with Personal Eye and Face Protection Devices. This standard protects people against specific hazards encountered in the workplace. The common hazards include blunt impact, radiation, splashes and droplets, dust, small dust particles, none of which protect against the hazards experienced when directly viewing the Sun. In fact, a word search on the Z87 shows that the word "eclipse" isn't anywhere in the standard itself. Also, some people may be tempted to simply take two pairs of glasses and stack them on top of each other with the thought that this would provide sufficient protection. This is the scenario that was tested with the data in "None3+4," which will still not provide anywhere close to sufficient protection.

3.5 Figures

FIGURE 3.5: 100W incandescent light bulb viewed through ISO+CE certified glasses

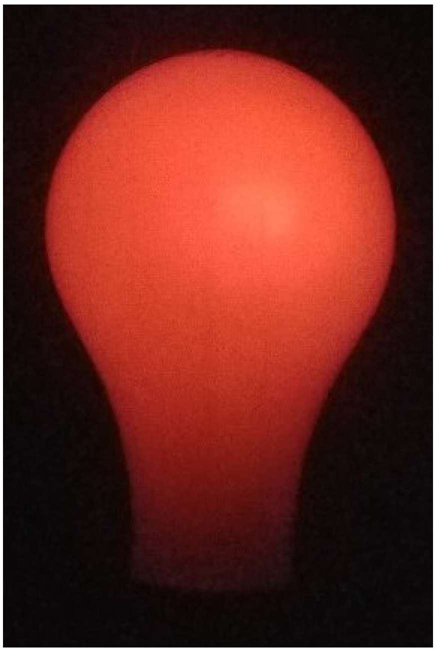

FIGURE 3.6: 100W incandescent light bulb viewed through China CE certified glasses

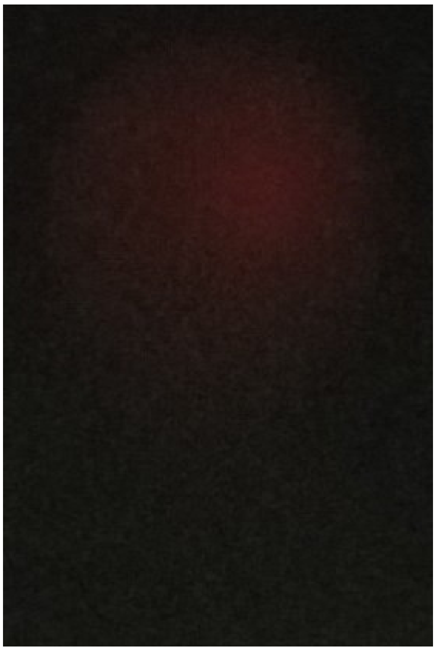

FIGURE 3.7: 100W incandescent light bulb viewed through UK CE certified glasses

FIGURE 3.8: 100W incandescent light bulb viewed through Non-certified glasses

Chapter 4

Conclusions

A study has been conducted on evaluating the suitability of different types of glasses for viewing the 2017 eclipse. As a result of said study, safe and unsafe types of glasses have been identified. All glasses that are ISO and CE certified will provide minimum recommended protection required to view the eclipse safely. In addition, to providing the minimum protection, the ISO and CE certified glasses do not have too high of an OD which would block out the Sun too much during the event. Some glasses that only have generic CE markings do not meet the minimum recommended protection level. Therefore this study does not recommend using eye protection that only has a generic CE marking.

If using welding glass, a Shade 14 will provide sufficient eye protection. It is speculated that Shade 12 will also provide sufficient protection (data not provided) albeit will be very uncomfortable to view due to the brightness of the Sun. The majority of retailers that are selling welding glasses when one types in “eclipse glasses” into a search bar will be Shade 5 which does not meet the recommended minimum OD and should be avoided.

Virtually all commercially available Sun glasses will not protect viewer’s eyes when viewing an eclipse, as they were not designed for directly viewing the Sun. Wearing multiple pairs will most likely increase the OD linearly, however one would need to wear close to 7 pairs to provide sufficient protection.

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